

DEVELOPMENT OF COMPUTER-BASED LABORATORY IN PHYSICS: CHARGING AND DISCHARGING OF A CAPACITOR

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Abstract— The purposes of this research was development of computer-based laboratory in physics using a computer interface experiment and computer simulation to study the charging and discharging of a capacitor. The interfaces are Arduino board, a resistor-capacitor circuit and relay circuit. The software is Arduino 0016 C++, Processing 1.0.9 and *Mathematica* 7. This is to experiment in measuring and modeling voltage on a capacitor and time while charging and discharging in real-time display. The result of the study was that the measuring voltage across the capacitor and time by computer interface experiment is equal to computer simulation. The average error of the time constant, which compared with the theoretical calculation, is less than 0.50 %.

Keywords— Computer Interface Experiment; Computer Simulation; Computer Based Laboratories; Charging and Discharging of a Capacitor; RC Circuit.

I. INTRODUCTION

MOST students agree: Physics is a difficult subject. The fact that there are many applications to contend with only complicates the learning process, such as formulas, calculations, graphs, experiments and conceptual explanations. (Angell et al, 2004)

An easier format may be applicable; computer simulations are applications which have aroused great interest in physics teaching. A well-known common factor is a PC unit with an interface and measuring sensors can be used as a measuring device, and for automation of measurements. Research has shown that traditional methods of teaching physics in schools have been unable to substantially alter student's perception of conceptual understanding. Although these methods should not be totally discarded; it has been observed that intensive studies did not achieve the objective of raising the test average.

However a new dawn is approaching CBL Computer-Based Laboratories. A simple set-up tool which has been developed to interface with Apple tools II and Macintosh computers coupled with a motion detector, force probe and temperature probe.

It has been observed that students thrive in the CBL learning environment, which is more likened to practicing scientists than the traditional school environment. The curricula and tools allow students to take an active role in their learning while encouraging them to construct knowledge from observation of the physical world. As a result of the simplified data collection process, even poorly prepared students are not perturbed, but encouraged to answer their own questions.

Group discussions ensue as the data is processed and displayed instantly using CBL tools.

The outline of this research is as follows: The material and methods are RC circuit theory, conceptual framework, computer interface experiment and simulation, result and discussion. The final topic contains concluding remarks.

II. MATERIALS AND METHODS

A. Computer Interface Experiment and Simulation

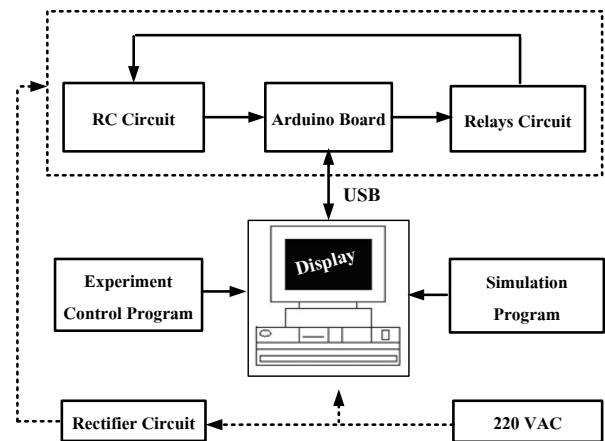


Fig.1 Computer interface experiment and simulation

Fig. 1 shows a computer interface experiment and simulation, which feature composes of hardware, software and performance. For hardware, A computer: Notebook Acer Aspire One : Intel® Atom™ Processor, USB port cable, Arduino board Interface : ET-Easy168 STAMP, AVR8 # ATMEGA168 16 KBYTE FLASH, SRAM 1 KBYTE, EEPROM 512 BYTE, shown Fig. 2. Figure 3 shows a computer interface circuit between RC circuit, 12 VDC power source, relay circuit and Arduino board. Figure 4 shows a computer interface experiment of charging and discharging a capacitor in real time physics teaching. For software, the operating system is Windows 2007 Profession. The control program and display experiment are Arduino 0016 C++ and processing 1.0.9 C++. The simulation and analysis results program are written in *Mathematica* 7.

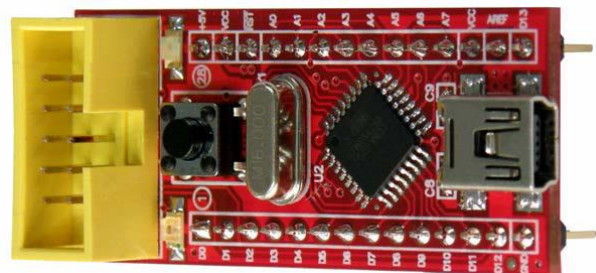


Fig. 2 Arduino board interface

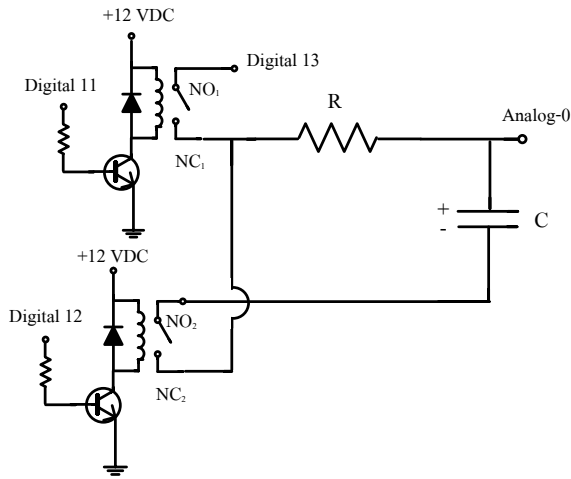


Fig. 3 Computer interface circuit, RC circuit, 12 VDC, power source, relay circuit and Arduino board.



Fig. 4 : Computer interface experiment of charging and discharging of a capacitor in real time physics teaching.

B. RC Circuit theory

Figure 5 shows a simple circuit consisting of a DC voltage source, V_s , a double-throw switch, S , a resistor, R and a capacitor, C . The circuit is called an RC circuit. Initially, the capacitor is uncharged and the switch is in the middle position.

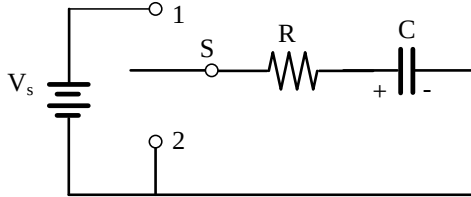


Fig. 5 RC circuit

The switch, S is closed as in the first position, at 1. Application of Kirchoff's Loop Law to the circuit above provides knowledge on the interaction between voltages, current, resistance and capacitance. See charging circuit equations below.

$$V_s - iR - \frac{q}{C} = 0 \quad (1)$$

By using differential equation calculus and the voltage across the capacitor, V_C increase with time. The voltage V_C as a function of time t is given by:

$$V_C(t) = V_s \left(1 - e^{-\frac{t}{RC}}\right) \quad (2)$$

where the exponential $e=2.718$ is the base of natural logarithm. The quantity $\tau=RC$ is called the time constant. The curve of the exponential rise in voltage with time during the charging process is illustrated in Fig. 6. At time $t=\tau=RC$ (one time constant), the voltage across the capacitor has grown to $0.63V_s$. After a period equivalent to 4 time constants, ($4T$) the capacitor in this RC charging circuit is virtually fully charged and the voltage across the capacitor is now approx 99% of its maximum value, $0.99V_s$. The time period taken for the capacitor to reach this $4T$ point is known as the Transient Period. After a time of $5T$ the capacitor is now fully charged and the voltage across the capacitor is equal to the supply voltage. As the capacitor is fully charged no more current flows in the circuit, the time period after this $5T$ point is known as the steady state period.

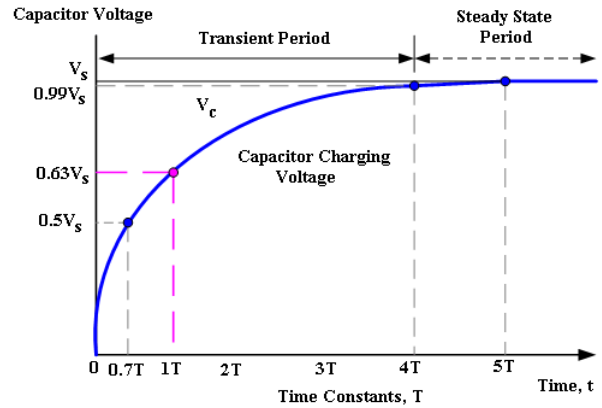


Fig. 6 RC charging curves

When a fully charged capacitor is discharged through a resistor, with the switch, S , in the second position, at 2, we get the following discharging circuit equation:

$$-iR - \frac{q}{C} = 0 \quad (3)$$

Deriving (2) we end up with:

$$V_C(t) = V_s e^{-\frac{t}{RC}} \quad (4)$$

The exponential decay of the voltage with time is also illustrated in Figure 7. After a time $t=\tau=RC$, the voltage across the capacitor has decreased to $0.37V_s$. After a time of $5T$ the voltage across the capacitor decaying to zero.

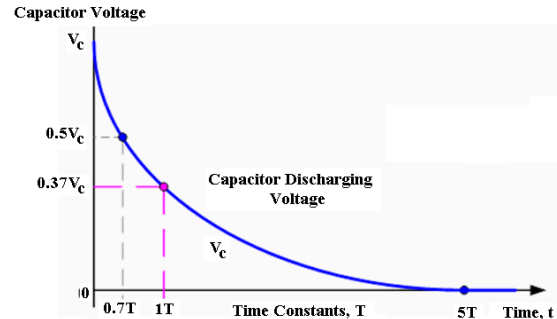


Fig. 7 RC discharging curves

C. Algorithm 1 computer interface experiment

Use the computer interface experiment of charging and discharging of a capacitor.

1. First, set up a circuit like the one shown in Fig. 3
 $R=2.2\text{ k}\Omega$ and $C=100\text{ }\mu\text{F}$
2. Connect the USB port cable to the Arduino board interface and connected to the computer.
3. Turn on the computer.
4. Run control program experiment for charging of a capacitor measuring values of capacitor voltage and time.
5. Record the time with millis, the voltage across the capacitor and the plot of voltage versus time in the graph display. When the voltage across the capacitor reaches steady state save data.
6. Repeat steps 4 and 5 above for the discharging case.
7. Repeat steps 4-6 with new values of C , which are $470\text{ }\mu\text{F}$, $1000\text{ }\mu\text{F}$ and $2200\text{ }\mu\text{F}$.

D. Algorithm 2 computer simulation

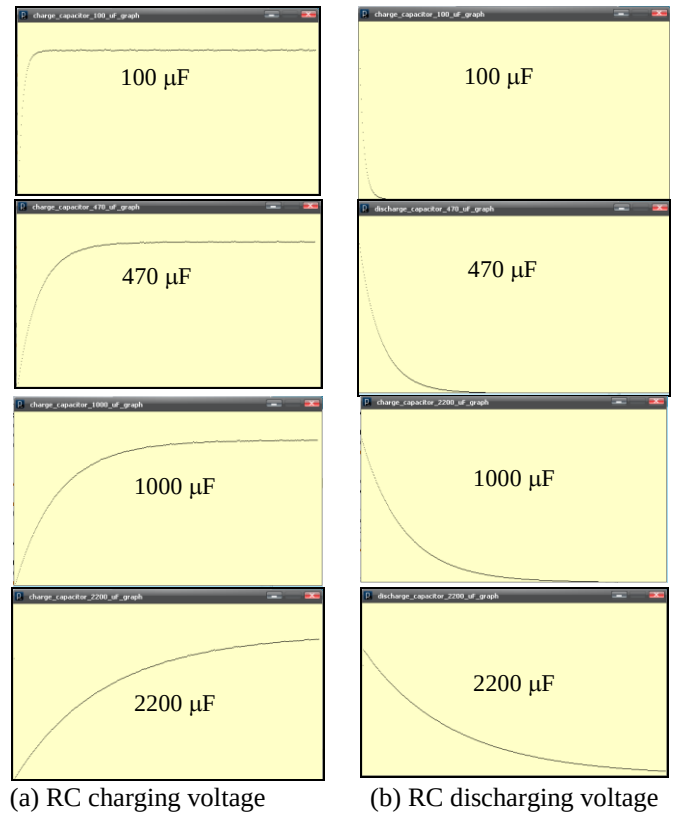
Use the computer simulation of charging and discharging of a capacitor.

1. Data input are $V_S = 5.0\text{ V}$, $R=2.2\text{ k}\Omega$ and $C=100\text{ }\mu\text{F}$.
2. Compute voltage across the capacitor from (2) for charging.
3. Compute voltage across the capacitor from (4) for discharging.
4. Result outputs are composed of voltage across the capacitors for charging and discharging.
5. Plot the voltage across the capacitor and time for the charging and discharging capacitor.
6. Repeat steps 2-5 with new values of C , which are $470\text{ }\mu\text{F}$, $1000\text{ }\mu\text{F}$ and $2200\text{ }\mu\text{F}$.
7. From the recorded data of the computer interface experiment find the times constant using matching data.

III. RESULT AND DISCUSSION

A graph in Fig. 8 shows the relationship between the capacitor voltage and time. The transient period increases as capacitance increase. The voltage begins at zero, rises rapidly and slowly approaches the V_S input, following the exponential form in Fig. 8 (a). The voltage begins at V_S decays exponentially approaches to zero in Fig. 8 (b). *Mathematica* 7 program was used to graph the voltage verses time, as RC circuits for analysis results, and compared with simulation. The results are shown in Fig. 9 and Fig. 10.

From Fig. 9 and Table I, this is clear that the voltage of the capacitor goes from 0 V to 5 V in about $5RC$ s. The voltage of the capacitor increases as soon as the change starts to build up, this reduces the voltage across the resistor and therefore reduces the charging current. This means that the rate of charging becomes progressively slower.



(a) RC charging voltage

(b) RC discharging voltage

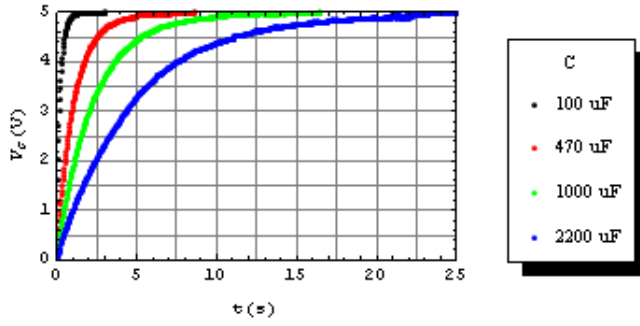
Fig. 8 Computer Interface Experiment measured values of capacitor voltage and time for the charging and discharging, which the resistance is fixed but the capacitance varies with $V_S=5.0\text{ V}$ and $R=2.2\text{ k}\Omega$.

TABLE I TIME CONSTANT

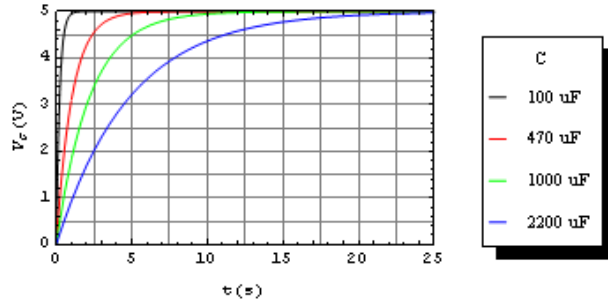
C (μF) /Tim(s)	0.7R	1RC	2RC	3RC	4RC	5RC
100	0.154	0.22	0.44	0.66	0.88	1.10
470	0.721	1.03	2.06	3.09	4.12	5.15
1000	1.540	2.20	4.40	6.60	8.80	11.0
2200	3.388	4.84	9.68	14.52	19.36	24.20

The time constants are calculate from $R \times C$ in Table I.

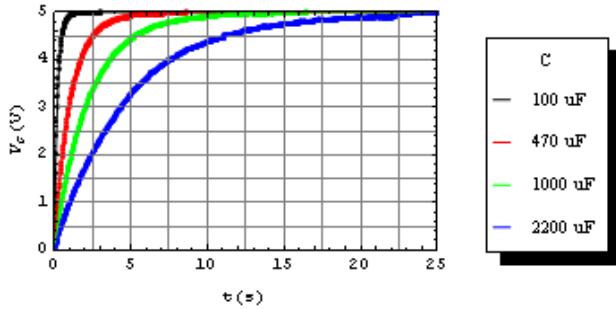
Figure 10 and Table I, it is clear to see that the capacitor discharges from 5 V to 0 in about $5RC$ s. At first the current is large because the voltage is large, so charge is lost quickly and the voltage decreases rapidly. As charge is lost the voltage is reduced making the current smaller so the rate of discharging becomes progressively slower.



(a) Computer interface experiment



(b) Simulation using (2)



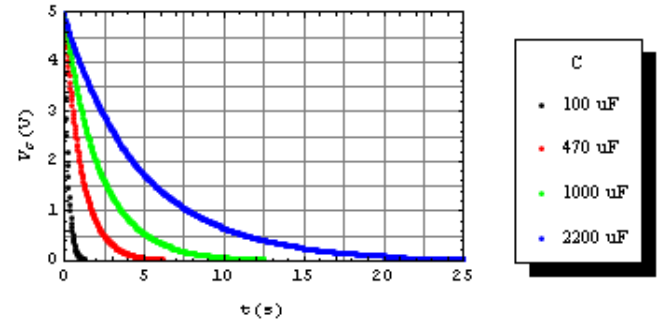
(c) Experiment and simulation
Fig. 9 Capacitor charging voltage

The equations (2) and (4) are a non-linear equation. Transform this equation so that it can be interpreted as linear.

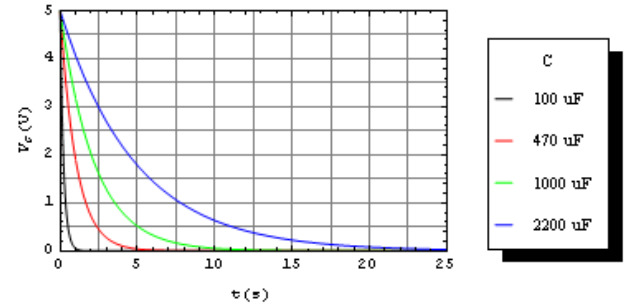
$$\text{Charging} \quad \ln\left(1 - \frac{V_C(t)}{V_s}\right) = -\frac{1}{RC}t \quad (5)$$

$$\text{Discharging} \quad \ln\left(\frac{V_C(t)}{V_s}\right) = -\frac{1}{RC}t \quad (6)$$

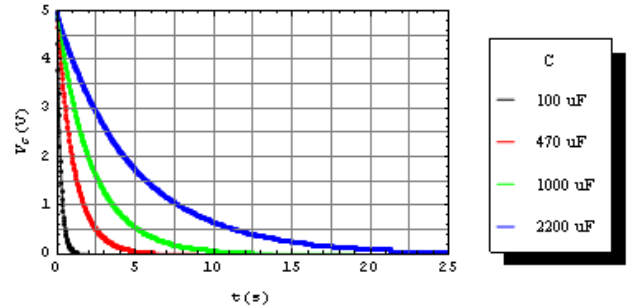
The slope of graph is equal to $-1/RC$. From the slope of the graph, determining the experimental time constant for the RC circuit, which is useful for determining an unknown R if C is known or determining an unknown C if R is known.



(a) Computer interface experiment



(b) Simulation using (4)



(c) Experiment and simulation
Figure 10. Capacitor discharging voltage

Figure 11 plots the graph between $\ln\left(1 - \frac{V_C(t)}{V_s}\right)$ and time for charging experiment and plot the linear fit, the equations of a straight line as shown (7)-(10).

$$\ln\left(1 - \frac{V_C(t)}{V_s}\right) = -4.53979t \quad (7)$$

$$\ln\left(1 - \frac{V_C(t)}{V_s}\right) = -0.97119t \quad (8)$$

$$\ln\left(1 - \frac{V_C(t)}{V_s}\right) = -0.45240t \quad (9)$$

$$\ln\left(1 - \frac{V_C(t)}{V_s}\right) = -0.20695t \quad (10)$$

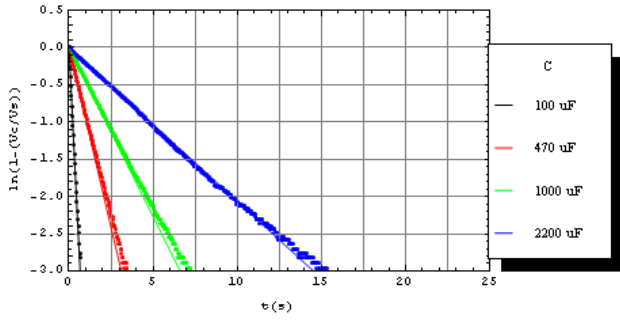


Fig. 11 The graph between $\ln\left(1 - \frac{V_C(t)}{V_S}\right)$ and time for charging experiment and plot the linear fit.

Figure 12 plots the graph between $\ln\left(\frac{V_C(t)}{V_S}\right)$ and time for each discharging experiment and plot the linear path, the equations of a straight line shown (11)-(14).

$$\ln\left(\frac{V_C(t)}{V_S}\right) = -4.52422t \quad (11)$$

$$\ln\left(\frac{V_C(t)}{V_S}\right) = -0.97175t \quad (12)$$

$$\ln\left(\frac{V_C(t)}{V_S}\right) = -0.45341t \quad (13)$$

$$\ln\left(\frac{V_C(t)}{V_S}\right) = -0.20733t \quad (14)$$

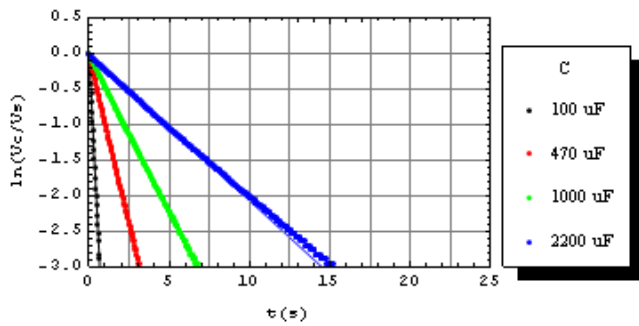


Fig. 12 The graph between $\ln\left(\frac{V_C(t)}{V_S}\right)$ and time for discharging experiment and plot the linear fit.

Compare the correct values for both changing and discharging time constants to the calculated values. From Table II, we can see the RC of the calculated by $R \times C$ agree with the experimental data for all the capacitance. The

average error of the RC, which compared with the theoretical calculation, is less than 0.50 %.

Table II Time Constant

C (μF)	$R \times C$ (s)	Experimental time constant (s)		Average value of RC	Error (%)
		Charging	Dis- charging		
100	0.22	0.22027	0.22103	0.22065	0.2954
470	1.03	1.02966	1.02907	1.02937	0.0612
1000	2.20	2.21043	2.20551	2.20797	0.3623
2200	4.84	4.83209	4.82322	4.82766	0.2549

The time constant are shown in Table II, which the time constants are calculated from the slope of the graph in Fig.11 and Fig.12.

IV. CONCLUSION

This research was development of computer-based laboratory in physics using a computer interface experiment and computer simulation to study the charging and discharging of a capacitor through a resistor by measuring the voltage drop across the capacitor as a function of time and determine the RC time constants. This results recorded from the experimental data shows that simulation and theory are aligned. The average error of the RC, which compared with the theoretical calculation, is less than 0.50 %. A computer-based laboratory is applications in real time physics teaching which helps students comprehend physics conception and law. These tools are applied in variety of appropriate tasks. In the future it is my desire to do further studies on development in physics instruction on Constructivist with computer-based laboratory.

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